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PRELIMINARY OPERATIONAL RESULTS FROM THE WILLARD SOLAR POWER SYSTEM

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ABSTRACT

The solar-powered system located near Willard, New Mexico, generates mechanical or electrical power at a capacity of 19kw (25 HP). The solar collection system incorporates east/west tracking parabolic trough collectors with a total aperture area of 1275m^2 (13720 ft^2). The hot oil type thermal energy storage is sufficient for approximately 20 hours of power system operation. The system utilizes a reaction-type turbine in conjunction with an organic Rankine cycle engine. Total collector field efficiency reaches a maximum of 20 percent near the winter solstice and about 50 percent during the summer. During the month of July, 1979, the system pumped 60 percent of the 35,300m^3 (28.6 acre-feet) of water delivered. Operating efficiencies for the turbine component, organic Rankine cycle engine and the complete power system are respectively 65-75 percent, 12-15 percent and 5-6 percent. Significant maintenance time was expended on both the collector and power systems throughout the operational period.

INTRODUCTION

The Willard solar power system provides both mechanical and electrical power with a capacity of 19kw (25 HP). The major application of the power system is the operation of a shallow-well irrigation system and the production of electrical power when pumping is not required. The power system is located near Willard, New Mexico on a commercial farm in the Estancia Valley.

Estimates indicate that irrigation farmers in New Mexico use 430,000m^3 (15 million ft^3) of natural gas per year for pumping water (1). Arizona uses an equal amount and Texas about four times as much. These three states also use large quantities of electrical power where a large portion is generated from natural gas. Although the short-term supply appears adequate, the cost has escalated fivefold in the past six years and has consequently imposed an extreme cost "squeeze" on irrigation farmers. In the near future, the supply of natural gas to farmers is expected to dwindle to the point that the fuel will undergo curtailment for power applications. With this event, solar power systems under development now will provide one of several available alternatives.

POWER SYSTEM DESCRIPTION

The Willard power system generates a power output (mechanical or electrical) of 19kw. A belt-driven induction generator provides electrical

power when mechanical power for irrigation is not required. Table 1 summarizes the basic specifications and Figure 1 is a schematic diagram of the system showing the major components.

Table 1

WILLARD POWER SYSTEM SPECIFICATIONS

Location:	Estancia Valley, near Willard, New Mexico latitude, 34.2°; elevation, 1835m (6019 ft)
Irrigation:	Well depth, 32 m (105 ft); holding pond capacity, 5,560m^3 (4.5 acre. ft); area, 150, 000m^2 (120 acres).
Solar Energy Collection:	Parabolic trough, north-south axis, east/west tracking; Solar Kinetics collector field area, 651m^2 (7000 ft^2); aperture width 2.1 m (7 ft); Accurex collector field area, 625m^2 (6720 ft^2; aperture width 1.8m (6 ft) heat transfer fluid, Caloria HT 43; maximum collector recirculation temperature, 216°C (420°F); storage tank volume, 51.9m^3 (13720 gal).
Power System:	Working fluid, R113; peak boiler conditions, 163°C (325°F) and 1550 kPa (255 psia); condensing water, less than 16°C (60°F); condenser conditions, 30°C (86°F) and 55kPa (8 psia turbine); turbine, single-stage, radial-inflow, reaction-type, 99mm (3.9 in) diameter, 36,300 RPM rotational speed; gearbox, two-stage, 1800 RPM rotational speed.

The system can be operated in three modes:

- °Solar energy to storage
- °Solar energy to power system
- °Energy from storage to power system

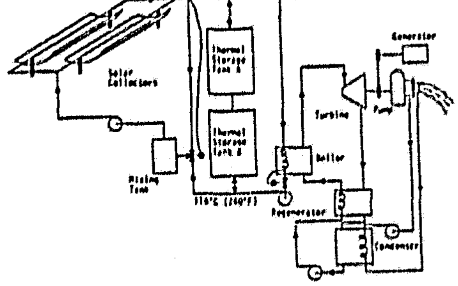

FIGURE 1. SCHEMATIC DIAGRAM OF THE WILLARD SOLAR POWER SYSTEM

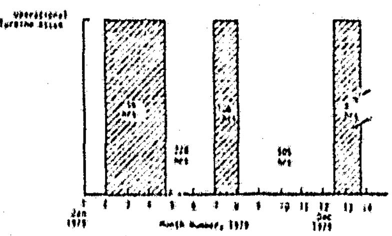

FIGURE 2. AVAILABILITY OF TURBINE ASSEMBLY FOR SYSTEM OPERATION

The greatest stability in power system operation occurs when drawing energy from storage -- the high temperature is relatively stable. Operating the power system from the solar collector field presents varying

conditions in addition to the possibility of shut-down as a function of weather conditions. Automatic switching exists within the control system but requires refinement as significant temperature excursions occur at the boiler (pool-type) once a mode change is made. Power system shut-down is also automatic when energy (sufficiently high oil temperature) is unavailable.

OPERATIONAL PERFORMANCE

The Willard power system was operated during the 1979 growing season to provide irrigation water. Figure 2 shows the operational times to date of the turbine assembly and the complete power system. Those times when the turbine assembly is under repair, an orifice plate substitutes in place of the turbine. In this way, the remainder of the power system functions in the usual way. The times within the "bars" on Figure 2 are the system hours with the turbine assembly and those times outside the hours on the system without the turbine.

The solar fraction (pumped water divided by total water pumped) is given in Figure 3 for the operational period through July where the turbine was installed in the system. The thickness of the lines on the plot incorporate the experimental uncertainties associated with the calculation. Also, as the data is largely based on manually recorded data, the time intervals are resolved to the point where both water flow and power system data correspond. The average solar fraction for this time period is 0.6 relative to the total water pumped of 35,300m^3 (28.6 acre-feet).

Reviewing the operation of specific components, the collection system will first be presented. Figure 4 shows the ratio of the actual time the collectors were in operation to that of the maximum time possible on an average monthly basis. These operational times are based on clocks installed within the electrical control system of the collectors. Therefore, the control pyranometer indicating when collection is possible yields the maximum time and the actual time is measured from the tracking circuitry. This ratio is less than unity for several reasons including abnormally high wind speeds and maintenance. The value calculated for August is based only on approximately 20 hours of operating time and thus not representative. The remaining months are based, however, on the total hours for that specific month. For the total hours of collector operation thus far, the time ratio is 0.73.

Figure 5 shows the normalized direct beam component of solar insolation resolved in the plane of the collector aperture as east/west tracking occurs. Separate curves are shown for the winter and summer solstice (2). Clear days are assumed in the calculation. Because of the collector orientation, the winter solar insolation collected decreases in the vicinity of solar noon. As the summer solstice is approached, the beam component of the solar insolation striking the collector becomes nearly uniform throughout the day as well as increasing in magnitude.

Typical operation of the Willard collector field results in efficiencies such as those given in Figure 6 for January 4, 1980. Between the times

1400 and 1410, the collector field changed from the re-circulation mode to the storage mode (introducing hot oil to storage). Note that during the re-circulation mode, the collector efficiencies are low while for storage, the efficiencies greatly increase. The cause of this increase is the relatively low temperature difference across the respective collector fields when in the re-circulation mode. The total field efficiency falls between the two extremes established by the Accurex and Solar Kinetics collector fields. During summer operation, the total field efficiency routinely approached 50 percent.

A partial explanation for the disparity in collector efficiency for the two collector fields is given in Figure 7. The total reflectivity of the

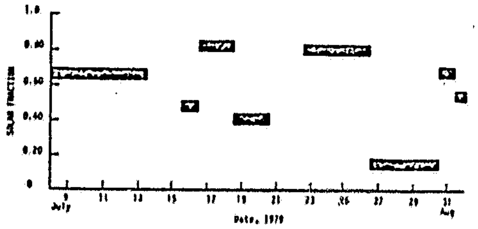

FIGURE 3. SOLAR FRACTION FOR IRRIGATION PUMPING

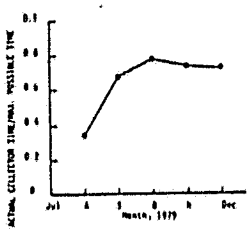

FIGURE 4. OPERATIONAL SUMMARY OF WILLARD COLLECTOR FIELD

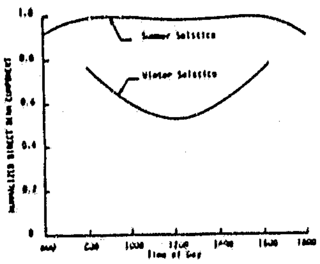

FIGURE 5. VARIATION OF NORMALIZED DIRECT BEAM COMPONENT OF SOLAR INSOLATION RESOLVED IN PLANE OF COLLECTOR APERTURE

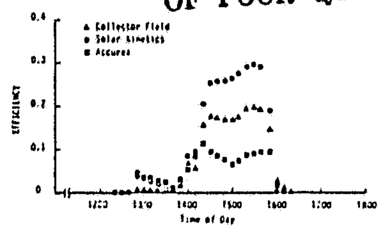

FIGURE 6. VARIATION OF COLLECTOR EFFICIENCY ON JANUARY 4, 1980

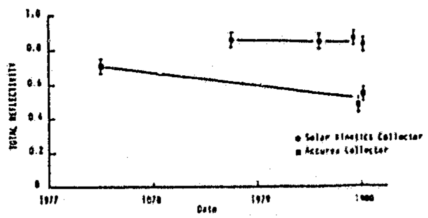

FIGURE 7. COLLECTOR SURFACE TOTAL REFLECTIVITY

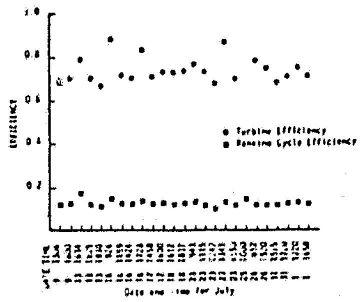

FIGURE 8. TURBINE AND RANKINE EFFICIENCIES FOR THE WILLARD POWER SYSTEM DURING JULY 1979

collector's reflective surface is shown as a a function of time. These measurements must be considered approximate and appropriate error limits

are indicated on each of the measurement points (3). The actual measurement involves a portable instrument incorporating a light source varying between 350-750 nanometers where the illuminated portion is visually observed at an angle of 20°. The reduced reflectivity of the Accurex polished aluminum surface appears to account for part of the reduced performance of the collector.

For the July operational period, Figure 8 shows the turbine component and Rankine cycle efficiency. The turbine efficiency is based on the ideal case of isentropic flow while the Rankine cycle efficiency is based on the measured output power. While the turbine efficiency bounces in the lower 70's the Rankine efficiency varies between about 12 to 15 percent. The overall system efficiency for this time period is thus in the vicinity of 5 to 6 percent (output power is divided by direct beam solar insolation input).

A summary of the maintenance performed on the system is given in Figure 9. The major items are the non-routine activities associated with the collection system and the organic Rankine cycle engine. These activities include such things as: modification of collector control equipment, receiver tube and glass shroud replacement, removal and installation of turbine assembly, repair and replacement of the R-113 feed pump and the replenishment of the R-113 inventory subsequent to significant leaks. As improvements are made with the equipment, the non-routine maintenance will decrease.

The crops planted and harvested over the 1979 growing season were alfalfa and timothy hay approximately $50{,}000 m^2$ (40 acres) each. Yields were normal for the location and weather conditions.

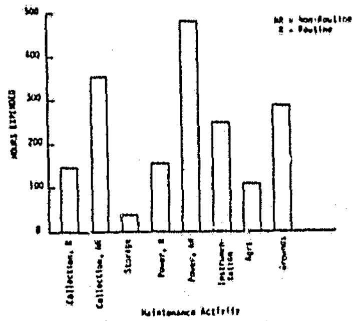

FIGURE 9. MAINTENANCE SUMMARY OF WILLARD POWER SYSTEM FOR 1979

Acknowledgments

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